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BETWEEN PROTONS AND THE
INERT GASES

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THE POLARIZATION OF LYMAN ALPHA RADIATION PRODUCED IN CHARGE
TRANSFER COLLISIONS BETWEEN PROTONS AND THE INERT GASES[†]

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ABSTRACT

The polarization of Lyman alpha radiation arising from charge transfer collisions between protons and helium, argon, and neon has been measured for incident proton energies from 0.6 to 24 keV. A lithium fluoride crystal set at the Brewster's angle was used to measure the polarization of the radiation. Structure has been observed in the energy dependence of the polarization fraction for H^+ -Ne and H^+ -Ar collisions which reflects the structure in the total cross sections for electron capture into the 2P state of atomic hydrogen for these collisions. The present results are in poor agreement with those of Gaily et al.

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INTRODUCTION

Over the past decade considerable attention has been devoted to the measurement of cross sections for charge transfer into the 2P state of atomic hydrogen for collisions of the type



where R is an inert gas atom.¹⁻⁶ It is now firmly established that the cross sections for H^+ -Ne and H^+ -Ar collisions show two maxima. A theory of excitation via an intermediate state has been proposed⁷ which helps to qualitatively explain the structure in these cross sections. The measurement of the polarization fraction of the emitted radiation will assist in both the understanding and analysis of the collision process.

In general the cross sections for charge transfer into the 2P state of the hydrogen atom have been computed from observations of the resonance radiation which arises when the excited atom decays to the ground state where the photons were detected at 90° with respect to the proton beam direction. If Q_{90} is the apparent cross section, assuming that the radiation is emitted isotropically, and Q_T is the total cross section, then it can be shown that

$$Q_T = Q_{90}(1 - P/3) \quad (2)$$

where the polarization fraction P is defined as

$$P = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}} \quad (3)$$

I_{\parallel} and I_{\perp} are the intensities of the radiation viewed at 90° to the incident beam direction with their electric vectors oscillating parallel and perpendicular to the direction of the proton beam.

Until quite recently the measurement of the polarization of Lyman alpha radiation has been made by measuring the angular distribution of the radiation.

For electric dipole radiation the intensity at an angle θ to the incident beam direction is related to the total intensity by

$$I(\theta) = \frac{3I_{\text{T}} (1 - P \cos^2 \theta)}{4\pi (3 - P)} . \quad (4)$$

The measurement of intensity as a function of angle has been used to obtain polarizations in electron-hydrogen atom collisions⁸ and in heavy particle collisions.^{9,10}

The development of a polarization analyzer¹¹ which consists of a reflecting lithium fluoride crystal set at the Brewster's angle has enabled us to measure the polarization directly from the definition. The present results are compared with a previous measurement⁹ and are found to disagree, yet the present results appear to be consistent with the theory of Poluektov and Presnyakov⁷ which takes into account excitation via an intermediate state.

EXPERIMENTAL APPROACH

The basic experimental apparatus has been described in the preceding paper.¹² In most of the present measurements a dc technique was used where the inert gas under study was admitted to the collision chamber to attain pressures on the order of 1×10^{-5} Torr. The background pressures in the chamber were typically 2×10^{-7} Torr. The interaction region viewed by the polarization analyzer was defined by collimating apertures between the analyzer and the proton beam.

The polarization analyzer was basically the same as that described in the previous paper with the major difference being that in these measurements the emitted radiation was observed at an angle of 90° to the proton beam direction (See Fig. 1). Therefore, the I_{\parallel} and I_{\perp} components of radiation, as defined in Eq. (3), were measured directly. The analyzer assembly had one other modification which enabled it to be rotated into the four positions 0° , 90° , 180° , and 270° with respect to the proton beam direction. In the 0° and 180° positions the I_{\perp} component of radiation was detected, while the I_{\parallel} component was detected in the 90° and 270° positions.

The experimental procedure was to make several measurements in each of the four analyzer positions with the inert gas in the chamber. Then, measurements were also made with no inert gas admitted to the chamber in order to determine the dc signal arising from the protons interacting with the normal background gas in the collision chamber. This small dc background signal was then subtracted from the signal obtained with the inert gas present to obtain the signal resulting from proton-inert gas collisions for each component of the observed radiation. The criterion for acceptability of the data was that the proton-inert gas signals should be equal for the 0° and 180° positions, and

for the 90° and 270° positions. The expression which was used to compute the polarization fraction was

$$P = \frac{1}{E} \left(\frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}} \right) \quad (5)$$

where E was the efficiency of the polarization analyzer, as measured by Ott et al.¹¹ to be 0.94, and I_{\parallel} and I_{\perp} were the proton-inert gas signals detected for the two components of the incident radiation.

In these measurements the recorded count rates were kept below 20 counts per second so that the number of counts lost due to the measured recovery time (500 microseconds) of the photon counter was at most 1%.

Several of the precautions that were taken to ensure that only the desired Lyman alpha was being detected have been mentioned in the previous paper. With the relatively high pressure of inert gas in the collision chamber in these dc measurements, it was also necessary to investigate whether collision quenching of H(2S) atoms was occurring in view of the analyzer. This investigation was made by using a modulated beam of argon atoms for some polarization measurements. Since the background pressure in the collision region was two orders of magnitude less under these conditions than when using the dc technique, the effect of collision quenching, if it were occurring, would have been readily apparent in a comparison of the data. The results of these measurements are discussed in the next section.

RESULTS AND DISCUSSION

The results of the polarization measurements for proton collisions with argon, neon, and helium are shown in Figs. 2-4. Several measurements for deuteron-argon collisions are also shown in Fig. 2 and have been plotted at one half their energy so that they may be compared with the proton data. The error bars represent plus and minus one standard deviation of the data.

The polarization results of Gaily et al.⁹ are shown in Figs. 2-4 for comparison with the present results. For protons incident on argon and neon at energies greater than 2 keV good agreement is found in the shapes of the polarization energy dependence. However, there is a serious discrepancy of about 0.15 in the absolute values of the polarization fraction. In addition, the minima at low energies are not as pronounced in the data of Gaily et al. A further discrepancy has been found in comparing the H^+ -He results, in that the shapes of the polarization energy dependence are not similar. The comparison between the two sets of results seems to indicate the presence of some systematic error in either or both of the experiments.

In an attempt to resolve the discrepancy between the two sets of measurements, further investigations were undertaken in the present experiment. Since Gaily et al. had not used an oxygen filter with their iodine-vapor-filled uv photon counter, the first investigation made was to evacuate the oxygen filter used in the present experiment and make several remeasurements of the polarization for proton-argon collisions. Agreement was found with our measurements made using oxygen in the filter.

Another test performed was to analyze the radiation resulting from collisions of protons with a modulated argon beam. The polarization fractions obtained were $P = -0.057 \pm 0.073$ at 10 keV and $P = 0.022 \pm 0.077$ at 3 keV

which overlap the more precisely determined values obtained with the dc technique in our experiments and disagree with the results of Gaily et al.

In another investigation the position of the analyzer assembly was changed so that it could analyze the radiation emitted at 54.7° to the proton beam direction. In this case Eq. (6) from the previous paper¹² was used to calculate the polarization. The results obtained were in good agreement with those taken with the analyzer in the position to observe radiation at 90° to the proton beam. In view of the consistencies in our measurements we believe that the experiments of Gaily et al. were subject to unidentified systematic errors.

The H^+-Ar and H^+-Ne measurements in the present experiments show pronounced structure, both exhibiting a minimum at low proton energies after which the polarization fraction rises very rapidly to a maximum value. The polarization fraction then decreases and remains negative up to the highest energies used.

The similarity in the polarization curves for the argon and neon collisions is reflected in the shapes of the total cross section curves for electron capture into the 2P state of atomic hydrogen. The total cross sections measured by Pretzer et al.² are shown as solid lines in Figs. 2-4. The largest polarizations were observed in the immediate vicinity of the low energy maximum in the cross section. Poluektov and Presnyakov⁷ have attributed the low energy maximum in proton-neon collisions to charge transfer via the intermediate 1S state in atomic hydrogen. The maximum at higher energies is attributed to a direct charge transfer process. Our results indicate that these two processes lead to different populations of the magnetic substates of the 2P state of hydrogen atom.

The polarization of Lyman alpha arising from H^+ -He collisions is near zero at the low energies. A shallow minimum is observed between 6 and 8 keV after which the polarization increases and appears to reach a maximum at about 22 keV. This is consistent with the prediction of Poluektov and Presnyakov that the dominant contribution to the cross section in our energy range is made by charge transfer through the intermediate state.

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FIGURE CAPTIONS

1. Schematic of the experiment.
2. Experimental values for the polarization of Lyman alpha radiation produced in H^+ -Ar and D^+ -Ar charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.
3. Experimental values for the polarization of Lyman alpha radiation produced in H^+ -Ne charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.
4. Experimental values for the polarization of Lyman alpha radiation produced in H^+ -He charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.

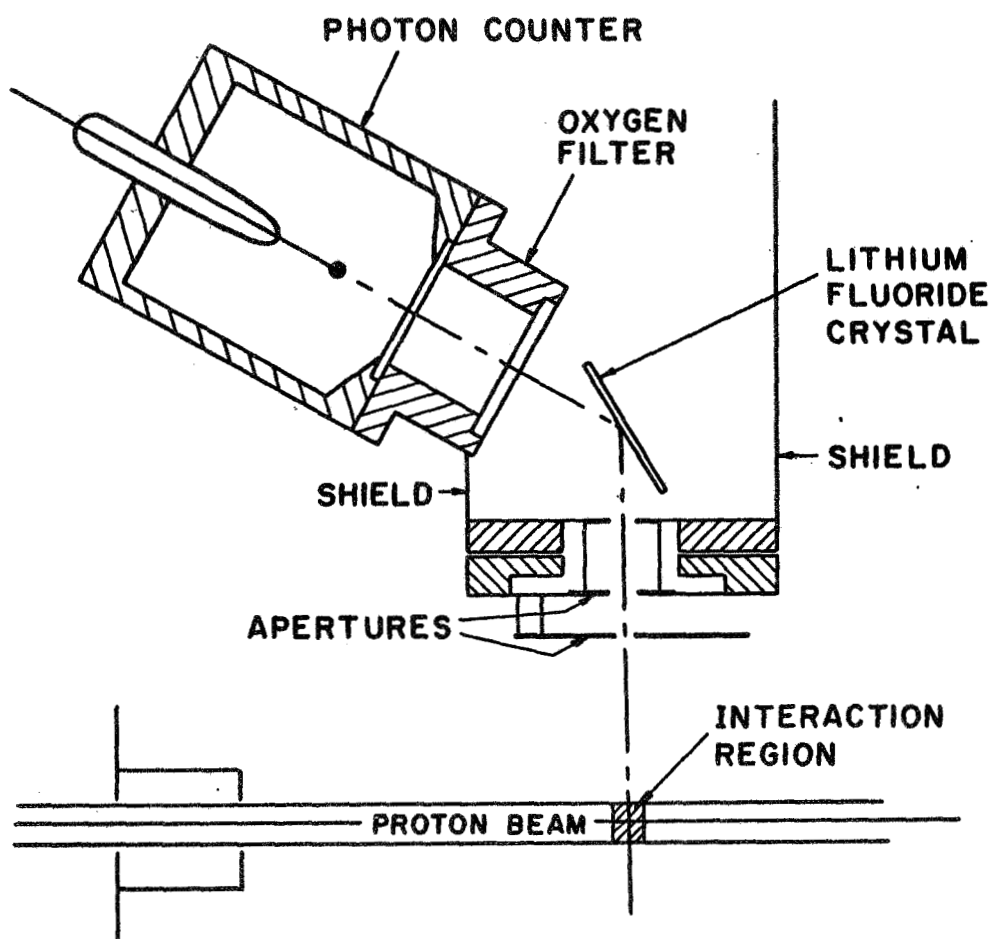


Figure 1. Schematic of the experiment.

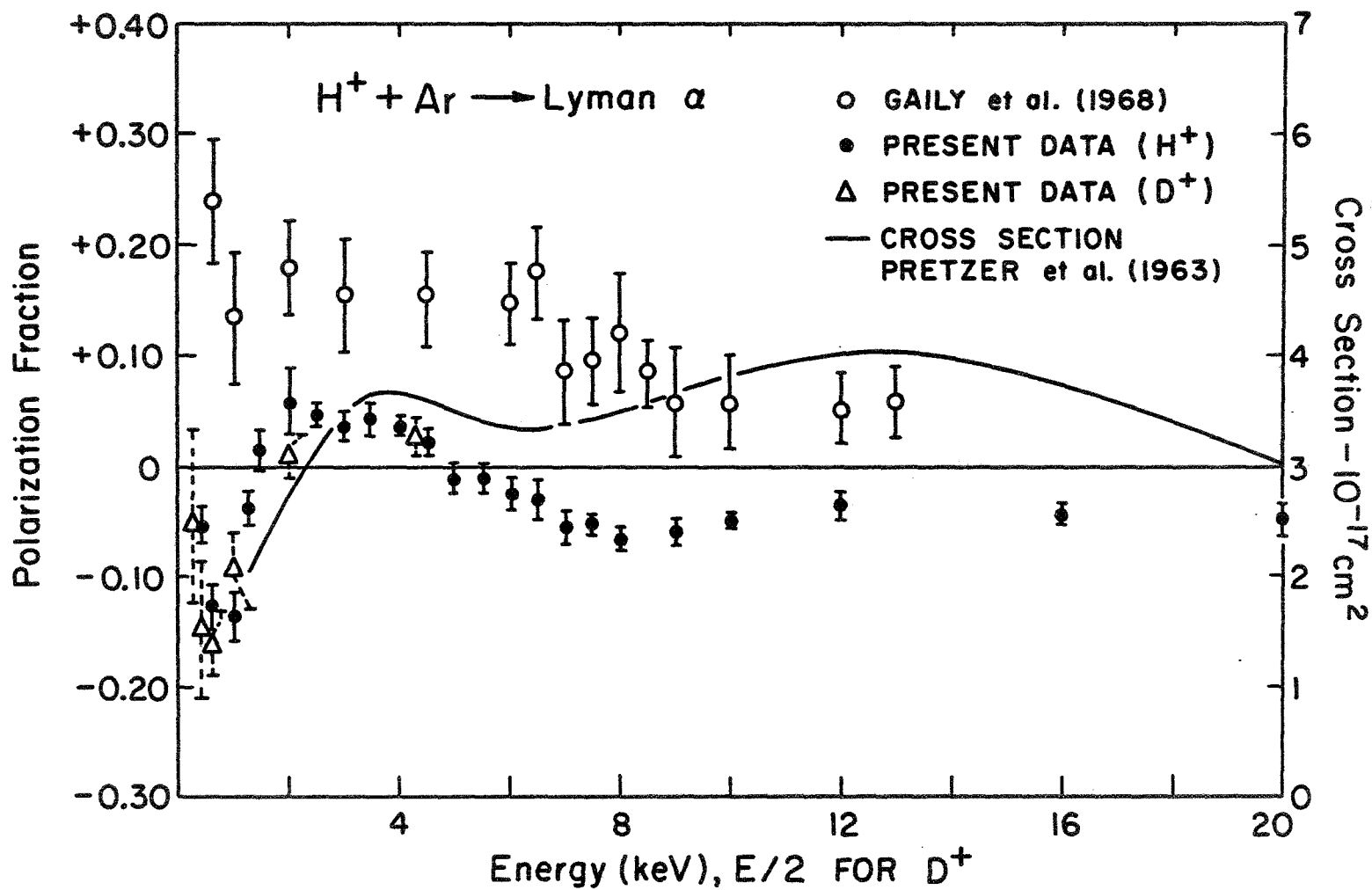


Figure 2. Experimental values for the polarization of Lyman alpha radiation produced in H^+ -Ar and D^+ -Ar charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.

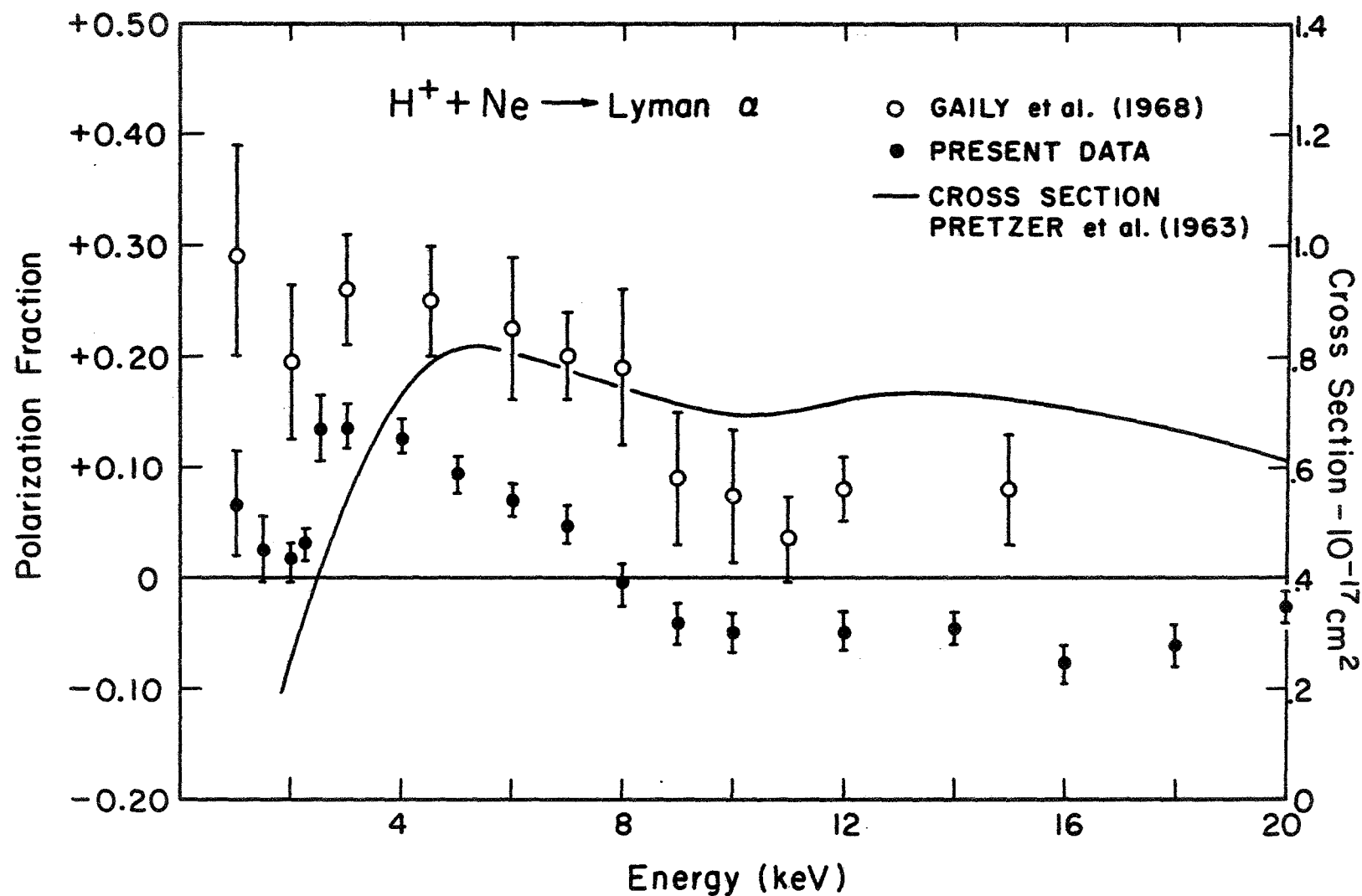


Figure 3. Experimental values for the polarization of Lyman alpha radiation produced in $H^+ - Ne$ charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.

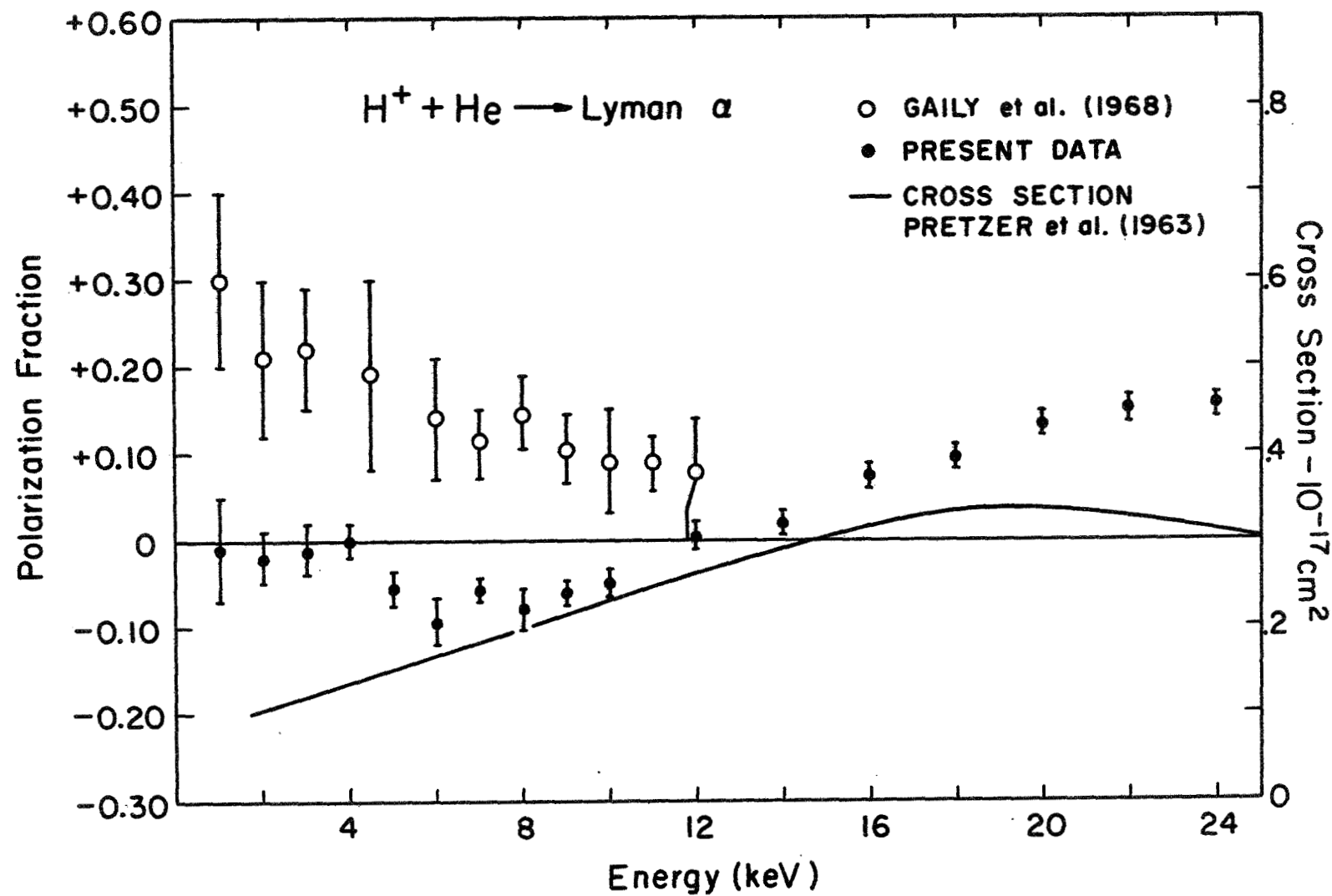


Figure 4. Experimental values for the polarization of Lyman alpha radiation produced in H^+-He charge transfer collisions compared with the polarization measurements of Gaily et al. and the cross section measurements of Pretzer et al.